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The effects of open head injury on intelligence test performance.

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by

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ABSTRACT

The long-term effects of well-localized penetrating head injury on standard intelligence test performance was explored. The relationship between age at injury and residual intellectual abilities was also investigated. Wechsler Intelligence Scales were administered to 80 brain-impaired veterans of World War II 15 years after injury. Wounds were classified according to side and locus of injury. Results suggest that a clear correspondence exists between hemisphere of injury and residual intellectual abilities. It was found that left hemisphere injury has a stronger effect on verbal abilities than right hemisphere injury on nonverbal visual-perceptual abilities. No clear relationship was established between locus of injury or age at injury and post-injury intellectual abilities. The implications of these findings on a general theory of cerebral organization and hemispheric asymmetry were discussed and suggestions were made for studying intellectual abilities in brain-injured samples in the future.

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Chapter I

INTRODUCTION

The purpose of the present study was to analyze systematically the long-term effects which penetrating missile wounds to the brain have on intellectual functioning. More specifically, this study was intended to examine the relationship between the site of the wound in the brain and residual verbal and nonverbal abilities. Standard measures of intelligence (Wechsler-Bellevue and Wechsler Adult Intelligence Scales) were employed as indices of these intellectual abilities. This study was designed to add to our present knowledge in two ways: (1) by studying the residual intellectual abilities of a sample which, to date, has been little studied, and (2) by illustrating the usefulness of multi-scale measures of intelligence for reflecting the effects of brain injury.

Based on the relevant literature in the neurosciences, it was thought that specific deficits in intellectual ability would depend largely on the locus of the brain lesion. In general, injury to the left cerebral hemisphere has been found to compromise verbal abilities. Similarly, wounds to the right hemisphere have been linked to specific deficits in visual-spatial, visual-constructional, and other nonverbal abilities (e.g., Newcombe, 1969; Reitan, 1955). In addition, the research suggests that the variable of age may play a role in the degree to which an individual is able to recover from behavioural loss after injury. For this reason, age at injury was also considered in the present analyses to explore its relationship with later intellectual functioning.

The effects of penetrating missile wounds on the brain are varied and complex. By studying subjects who have incurred such wounds, the unfortunate victims of the weapons of conventional warfare, neuroscientists have developed a fuller understanding and appreciation for the intricate workings of the human brain. In exploring the delicate issue of localization of function, these researchers have also gained some notion of the brain's ability to adapt to functional disorganization. However, little attention thus far has been directed to residual intellectual deficits and intellectual recovery following such injuries.

Traditionally, the diagnostic and rehabilitation issues for victims of open head injury have focused on gross physical, rather than behavioural, deficits. This has grown generally out of the medical model; more specifically, it is related to the emphasis in neurology on identifying "pathognomic" signs which can be classified according to specific treatment approaches. Included in the routine neurological assessment is a brief "mental status examination" -- a cursory and rather general evaluation of "higher-level" human functions such as language, memory, and thought. Recently, however, the burgeoning field of neuropsychology (and, to a lesser extent, physiological psychology) has developed its own set of behavioural measures designed to assess deficits and strengths in uniquely human behaviours. They tap skills of both basic level (sensory and motor) and higher-order processing of information (including the integration of sensory input and motor output, receptive and expressive language, verbal and nonverbal memory, thought, and more specific intellectual processes).

One experienced researcher in the study of open head injury has expressed his view in the following way: "I propose that we suspend our belief in the separateness of neurologic and behavioral signs and symptoms. Properly constructed psychophysical tests of sensory function or quantitative experimental tasks of problem solving or memorizing are extensions of the neurologic examination and just as relevant to assessment of brain function as is a careful reflex status. Such extended techniques ... can make otherwise silent lesions speak" (Teuber, 1969, p. 14). Only though the marriages of neurological and neuropsychological findings, together with fruitful approaches to personality assessment, can we hope to comprehend the functional complexities of the human brain and behaviour. In the case of penetrating head wounds (and other serious brain disorders), such an understanding is necessary if we are to treat the whole person successfully and realistically. The present study was intended to add to our present knowledge regarding the effects of penetrating missile wounds on several of the specific processes comprising "intellectual functioning". It is hoped that such information may contribute to an understanding of higher-order brain-behaviour relationships. Perhaps, in time, a fuller understanding of the localization functions may lead to better treatment and rehabilitation methods for persons sustaining damage to the brain.

In addition to an understanding of the degree to which certain functions are localized in the brain, it is essential to explore the brain's built-in abilities for partial functional recovery. Much clinical evidence has been gathered which suggests that the human organism is capable of some "healing" and adapting over time, such that behavioural deficits years after injury are much less debilitating than are those appearing immediately after injury. Developmental studies have suggested that the brain remains somewhat "plastic" in early childhood. This refers to the brain's ability to compensate and reorganize functionally in the event of certain types of structural and chemical damage. Much less attention, however, has been directed to expanding this developmental model throughout adolescence and adulthood by exploring what variables (e.g., age at injury) may contribute to differential rates of recovery in older persons. As previously mentioned, the present study was designed to examine the relationship between age and injury and subsequent recovery from injury. It must be kept in mind, however, that the subjects studied in the present analyses were tested 15 years after injury; for all practical purposes, therefore, the recovery process can be assumed to be complete. Perhaps with continued research along these lines, remediation and rehabilitation efforts may eventually be aimed at taking better advantage of the brain's natural abilities for functional reorganization.

LITERATURE REVIEW

Neurological Sequelae and Recovery Processes

In the past, many studies on open head injury were focused on exploring the physical sequelae of the wound. Walker and his colleagues (Walker & Erculei, 1968; Walker & Jablon, 1961) have conducted large-scale descriptive studies on head injured veterans of World War II and the Korean conflict. They concentrated primarily on the presence or absence of certain neurological signs (defects in somatosensory, motor, language, visual, and auditory systems) and post-traumatic symptomatology (epileptic seizures, subjective complaints of headaches, nervousness, and dizziness). Comparisons were based on various sites of injury within the wounded sample, as well as, between brain-damaged subjects and normal controls. These researchers have also considered general medical issues, such as differential mortality rates and causes of death in brain-injured populations (Walker & Erculei, 1968; Walker, Leuchs, Lechtape-Gruter, Caveness & Kretchman, 1971; Weiss, Caveness, Einsiedel-Lechtape & McNeel, 1982).

The neurological surveys found the most common problems to be various cranial nerve defects, followed by hemiplegia, aphasia, and hemianopsia. All deficits were found to be highly related to the location of cortical wounds (Walker & Erculei, 1968). "In all aspects of testing (including general measures of personality, overall intellectual functioning, and social adjustment), the neurologically defective individual fared less well than the neurologically normal individual." (p. 97) In comparing post-injury follow-ups at 5 and 15 years, little or no changes were detected in most of the gross neurological abnormalities, although the nature and incidence of post-traumatic epilepsy was found to change greatly, with a 40% remission rate in the 10-year period.

Much detailed research has been directed at discovering the unique variables which underlie the development and characteristics of post-traumatic epilepsy in victims of open head injury. In general, most researchers contend that post-traumatic epilepsy is a function of the severity of injury, as determined by depth of wound (Ascroft, 1941; Caviness, 1969; Walker & Joblon, 1961), post-injury infection of the wound (Caveness, Walker & Ascroft, 1962; Walker & Joblon, 1961), length of coma (Weiss & Caveness, 1972), and the concomitant occurrence of serious neurological impairments, such as mental deficits and hemiplegia (Caviness, 1969). Studies investigating the characteristics of the epileptic disorders (type of seizure, aura, and frequency of attacks) have resulted in a myriad of explanatory hypotheses, ranging from genetic factors (Tower, 1970) to complex physiological events causing early and late neuronal changes (Walker, 1969).

In addition to the data accumulated on the neurological sequelae, the research has been growing in the field of recovery and rehabilitation for the brain-injured. A.R. Luria and his colleagues in Russia have devoted much time and effort to the study of brain wounds incurred in war. In his 1948 monograph (1963 translation cited), Luria sets forth his theory on the processes of functional reorganization; he explains that this comes about through the "replacement of a lost cerebral link by another which is still intact" (1963, p. 55). Throughout his works, Luria emphasizes the importance of describing the nature of a functional deficit before designing a specific rehabilitation program for an individual. The intention is to take full advantage of those cortical systems which were unaffected by the wound. Using cases from his clinical war-time experience, Luria illustrates how motor and sensory losses can be compensated for by bringing previously automatic functions under conscious control (e.g., "talking through" a motor sequence of events). He further elucidates how this principle of changing the "psycho-physical composition" of an act can be applied to disorders of language and "gnostic" functions. Such complex behaviours are broken down into their component processes and subjects are retrained in a step-by-step fashion, employing whatever adaptive strategies are still intact. Although such methods should not be regarded as "miracle cures", they have proved to be quite useful for the severely wounded (Luria, 1975).

Variables related to differential rates of recovery following missile wounds have received little attention in the literature. Hurt and Teuber (as discussed in Teuber, 1975), however, have reported some interesting results relating to age at injury. They found that younger subjects (those aged 17 - 21 at time of injury) fared the best, showing the most improvement in motor and somatosensory functioning when tested 20 years after injury. Such findings suggest that other personal variables may account for differences in the rates and limits of recovery between individuals. These variables may well apply not only to an individual's natural recovery abilities, but also to one's responsiveness to intervention efforts.

Experimentation on Open Head Injured Subjects

Perceptual Abilities

In the decades following Luria's case study approach, missile injuries were studies in a much more systematic way, employing new psychophysical techniques and perceptual tasks. The team of Josephine Semmes, Sidney Weinstein, Lila Ghent, and Hans-Lukas Teuber pioneered the applications of this approach in their series of studies on sensory and perceptual functioning. They classified subjects according to site of lesion, as determined by entry of the missile. Comparisons were also made on the basis of clinical symptoms, such as visual field defects and sensorimotor impairments.

Their work on the effects of penetrating brain wounds culminated in a significant contribution to the theory of cerebral organization (Semmes, Weinstein, Ghent & Teuber, 1960). One hundred twenty-four brain injured and 33 control subjects with peripheral nerve injuries (to the leg) were compared on a number of somatosensory tasks of the right and left hands. Essentially, what Semmes et al. found was that, on tests of pressure sensitivity, two-point resolution, point localization, and passive movement of the fingers, sensory deficits were most highly correlated with posterior parietal lesions of the contralateral hemisphere. However, whereas right hemisphere brain lesions resulted in sensory deficits of the contralateral hand only, left hemisphere lesions were associated with <u>both</u> ipsilateral and contralateral sensory deficits (particularly on tests of point localization). That is, sensory deficits of the left hand resulted from lesions to either the right or left hemisphere; deficits of the right hand only resulted from left hemisphere damage. In addition, the right and left hands were found to differ in the nature of sensory deficit. While poor performances on the various sensory tasks were highly intercorrelated for the right hand, such impairments were not found to be associated with each other for the left hand (i.e., one might find left hand deficits in pressure sensitivity without associated impairments in point localization or passive movement). These results were interpreted that cerebral organization of somatosensory functions for the contralateral side is more diffusely represented in the right than left hemisphere.

In addition, Semmes et al. carried out separate analyses to test the hypothesis that the right-left sensorimotor differences "depend on the disturbances of more complex functions said to be associated with lesions of the left hemisphere" (p. 44) -- namely, dysphasic disorders and general intellectual impairment. Subjects who displayed signs of expressive or receptive language disturbances (as determined by the examiners' clinical judgments) were selected out and comparisons were made between the dysphasic and non-dysphasic subjects. No differences were found between these groups that would implicate language disturbances (e.g., verbal response confusion, failure to understand test requirements) as the primary cause of bilateral sensory deficits in the left-hemisphere-lesioned subjects.

Similarly, subjects showing intellectual loss on a standard intelligence test (Army General Classifications Test) were compared on the sensory tests to those considered to be intellectually intact. (The limitations of this test as a measure of general intelligence will be discussed in following sections.) The presence of intellectual loss was not found to be associated in any consistent way with increased sensory deficits, nor with greater incidence of bilateral sensory impairment.

The possibility that patterns of sensorimotor disturbance were due to widespread tissue damage in some subjects was tested by isolating those subjects with post-traumatic epilepsy. Subjects who had experienced at least one epileptic seizure since injury were considered in separate statistical analyses and compared against non-epileptic subjects on the sensory measures. No significant differences were found between these groups, thus rejecting the hypothesis that sensorimotor impairments were dependent on the presence of general brain disruption associated with an epileptic focus.

These researchers concluded that, in light of the careful considerations and analyses conducted, "We believe that our results cannot easily be dismissed as an artifact of the particular material and methods employed." (p. 53) However, in discussing the implications that such findings might have in reformulating popular theories of cerebral organization, these authors are cautious to point out that their results should not be generalized to other brain-damaged or normal populations without further experimentation.

In another study, Teuber and Liebert (1958) compared the abilities of open head injured subjects with normal controls on more complex sensory-perceptual tasks. Subjects were asked to adjust auditory and visual stimuli to specified positions in space (a sound source to an overhead position and a luminous line to its apparent vertical). All brain-injured subjects, regardless of site of damage, were found to be more strongly influenced by the starting positions of the stimuli than were normals. A similar across-the-board impairment was found in an open head injured group on a hidden figures task (Teuber & Weinstein, 1956). Corkin's (1979) findings suggest that this latter task is more sensitive to the size of lesion than to its locus in the cerebral hemispheres; also, poor performance on this task could not be attributed to general intellectual loss. In a later commentary on the post-traumatic consequences of missile wounds, Teuber (1969) proposed that such findings may be testament to either (1) the non-localization of these seemingly specific functions, or (2) the non-localization of the damage itself, which is usually classified merely on the basis of missile entry.

Clear hemispheric differences, however, have been demonstrated on other specific tasks of perceptual discrimination. In one study involving tactile size discrimination (Weinstein, 1962), subjects with unilateral injuries to the right hemisphere were found to perform significantly worse than subjects with left hemisphere lesions and normal controls. Also, the presence of deficits in two-point discrimination, regardless of site of lesion, was associated with impairments on this task (but to a lesser extent). "It appears that a combination of both factors results in the greatest frequency of defects in the tactile discrimination of three-dimensional size" (p. 176). Unilateral wounds were also found to produce impairments on a tactile test of pattern discrimination (Ghent, Weinstein, Semmes & Teuber, 1955). In this study, a wooden cube embossed with a given pattern was placed in each subject's palm for five seconds. Subjects were then asked to locate the same cube among an array of similarly-sized distractors by palpating each cube without the aid of vision. These researchers found that, while significant practice effects occur over repeated trials for the hand ipsilateral to the wound, the contralateral hand does not show significant changes (in time and error scores) over trials. These differences were not found to be related to lobe of injury or presence of sensory defects.

In a more complex task of tactual learning, right hemisphere lesions, particularly those in the temporal lobe, were associated with marked impairments (Teuber & Weinstein, 1954). Using a modified Seguin-Goddard formboard, these researchers blindfolded subjects and asked them to fit geometrically-shaped blocks into spaces on the board. A second trial, in which the board was turned 180°, resulted in significantly increased time scores for the right-lesioned group. Subjects with lesions in the left hemisphere performed similarly to normal controls. Teuber and Weinstein suggested that this study supports the notion that spatial abilities, including spatial memory, are localized in the right hemisphere. Similar conclusions were drawn after re-analysis of a size discrimination study conducted by Ghent and her colleagues (1955, as discussed in Newcombe, 1969).

More specific formulations of the localization hypothesis for spatial ability have been proposed by Semmes et al. (1963). In this study, personal body orientation was delineated from extra-personal spatial orientation (a locomotor maze task). Subjects with <u>left</u> posterior lesions fared the worst, as they were found to be impaired on both tasks. Subjects with left anterior lesions were impaired in personal body orientation only, while those with right posterior lesions were impaired on the extra-personal orientation task only. At first glance, these results may seem surprising. However, performance on these tasks obviously relies on one's ability to understand verbal instructions. The inferior performances found in the left posterior group may simply reflect deficits in receptive and organizational language skills associated with left posterior temporal lobe lesions. The impairments in the left anterior group may reflect difficulties in verbal mediation of behaviour which have been linked to lesions in this area.

Intellectual Abilities

In addition to studying the effects of penetrating head wounds on sensory and peceptual abilities, researchers have begun to investigate the repercussions of these wounds on higher-order intellectual abilities. Using the Army General Classifications Test (AGCT), a group-administered instrument considered to measure "general intelligence", Weinstein and Teuber (1957a) compared pre- and post-injury scores in both brain-injured and normal control veterans. The post-injury scores, taken 10 years after wounding (thereby allowing for natural recovery processes to be complete), showed that both the controls and many of the experimental subjects actually obtained higher scores on the test. In comparing subjects according to locus of injury, only those with left hemisphere parietal and temporal wounds evidenced declines in score. This same group effect was demonstrated even after aphasic subjects (as determined by neurologists' clinical judgments) had been excluded to control for the bias these deficits might have on AGCT performance.

These researchers concluded that their findings negate both (1) the "mass action" theory of intellectual functioning (an analogy based on Lashley's (1929) results in his animal research), and (2) Rylander's (1939) and Shure and Halstead's (1958) findings that intellectual impairment is maximal following injury to the frontal lobes. Weinstein and Teuber suggested in another study (1957b) that higher pre-morbid levels of intelligence are related to more demonstrable losses on measures of "general intelligence". In other words, it appears that a "floor effect" occurs with these measures such that no appreciable differences in performances can be detected, even years after injury.

In general, such research findings have been accepted as an indication of the relative insensitivity of general intelligence tests to the effects of penetrating missile wounds (Weinstein & Teuber, 1957a; Teuber, 1975). In contrast, Holmes (1958) has highlighted the notion that such test results are suggestive of cerebral localization for some functions. The very fact that the AGCT is a verbal test of intelligence lends support to the theory that verbal intellectual functions are subserved primarily by the left parietal and temporal regions. This finding is all the more significant in light of the results obtained after clinically dysphasic subjects had been excluded from the analyses; it would appear that damage to certain centres in the left hemisphere results in more subtle deficits in verbal intelligence than those detected by gross clinical measures of dysphasia. More recently, Lezak (1983) has reviewed the utility of the AGCT as a measure of general intelligence. She comments on its inherent limitations: a heavy relianve on verbal abilities and speed skills.

Problem-solving as a discrete intellectual function has been explored in head-injured veterans as well. Jarvie (1960) compared the performances of injured and normal control subjects on Raven's Progressive Matrices, the Hartford Retreat Test, and the Dominoes Test (an army selection test), all considered to be measures of non-verbal problem-solving ability. Severe deficits were found in 10% of his experimental group in comparison to their own pre-injury scores on these tests. For those subjects for whom pre-injury scores were not available, the Hartford Retreat Vocabulary Test, a measure tapping well-learned verbal abilities (similar to Wechsler's Vocabulary subtest), was used as a general index of pre-injury intellectual status. Jarvie warns, however, that this substitution may lead to an under-estimation of pre-morbid abilities in subjects with post-traumatic dysphasia. (The reverse might also be true for those veterans who returned to school after their injuries and upgraded their verbal skills, while other abilities remained impaired.) In addition, this researcher presents his results as "tentative" due to his lack of proper controls for dysphasia and dyscalculia -- conditions he believes might mask the expression of problem-solving abilities.

In terms of anatomical correlates, those subjects found to have problem-solving deficits were considered to represent cases of more extensive damage to subcortical white matter. These subjects had incurred either (1) deep anterior wounds of the brain, involving posterior frontal or anterior-parietal areas; these are considered to be brain centres highly concentrated with deep fiber tracts; or (2) through-and-through penetrating wounds, in which the missile had entered one hemisphere and exited the other; these are also considered to be indicative of white matter damage. Jarvie concluded that problem-solving ability can thus be viewed as a "mass action" brain phenomenon: The "diminished capacity for problem-solving shown by these men results from the isolation of different areas of the cerebral cortex from each other, rather than being due to damage to limited areas of cortex specifically concerned with this type of intellectual functioning." (p. 1380) Nonetheless, it is questionable whether the various skills demanded by each of Jarvie's three measures can be grouped together and labeled as problem-solving abilities only (ignoring, for example, the attentional skills needed to perform these tasks).

The question of how and what intellectual functions are compromised by which open head injuries has been addressed in more detailed fashion by other researchers. Russell and Espir (1961), for example, have written a descriptive work on the clinical assessment and practical aspects of rehabilitating language functions. Newcombe (1969) has gone a step further in her study of both verbal and nonverbal intellectual functioning following wounds to the brain. Twenty years after sustaining head injuries in World War II, Newcombe's subjects were administered 23 different measures tapping various intellectual skills. Both unilateral right and left hemisphere missile wounds were represented, in addition to well-age-matched hospital patient and veteran controls. The measures were grouped into five general areas of intellectual skill: (1) general intelligence and problem solving, (2) well-practiced verbal abilities, (3) verbal memory, including the processes of registration, retention, and recall, (4) visual pattern identification, and (5) spatial aptitude. Her results showed clear interhemispheric differences in the localization of verbal and nonverbal functions, as illustrated in the following summary points:

a) The experimental subjects did not evidence significant impariments (when compared to normal controls) on general intellectual functioning or problem-solving tests. This has been interpreted as an indication that such tests have only limited value in this area of neuropsychological research.

b) The left-hemisphere-lesioned group, regardless of area of primary damage, obtained lower scores on all verbal tests, in comparison to the right-lesioned group and control subjects. They showed the most impairment on a test of verbal fluency. However, after clinically-dysphasic subjects had been excluded from the statistical analyses, the experimental group (including cases of both right and left hemisphere damage) did not differ significantly from the controls on tasks of well-practiced verbal skills, such as vocabulary, spelling, and arithmetic tests.

c) The left-hemisphere-lesioned group showed "mild but consistent" deficits on tests of immediate and delayed verbal recall, in which digits, letters, syllables, words, sentences, and stories were used as stimulus items. In terms of site of lesion within the left hemisphere, subjects with parietal and "posterior" (occipital, temporo-occipital, and parieto-occipital) wounds were most impaired on paired-associate and other verbal learning tasks (involving repeated trials). Subjects with temporo-parietal lesions were most impaired on immediate recall "span" tests and short delay recall tasks. Subjects with "mixed" anterior lesions (fronto-temporal, fronto-parietal, and fronto-temporo-parietal) were most deficient on story recall tasks, while those with "pure" frontal lesions were found to be relatively free of verbal memory and learning deficits.

d) The right-hemisphere-lesioned group obtained lower, yet not statistically significant, performance scores on tasks assessing simple visual-matching ability and the recognition and learning of more complex visual patterns. A visual closure task, involving human faces as stimulus items, resulted in more severe impairments in the right-lesioned group. This was particularly pronounced in those subjects with right temporo-parietal lesions.

e) Right-hemisphere-lesioned subjects were clearly differentiated from those with left hemisphere damage and normal controls on a visually-guided maze learning task. The most severe impairments were found in subjects with right parietal and posterior lesions, supporting the results obtained by others on this task (Semmes, et al., 1963). Mild impairments were also noted in the right-lesioned group on a block design test.

Newcombe speculated further that "the evidence may indeed underestimate the extent of functional differentiation in the cortex, as it is derived from a study of men with chronic lesions, who have been learning for over two decades to overcome their handicaps. Even so, there was a clear dissociation of symptoms, implying that language functions are mediated by the left hemisphere and visual-spatial functions by the right hemisphere, although less exclusively." (1969, p. 120).

Such a "double dissociation of symptoms" between the right and left hemispheres strongly supports the theories of localization of function and asymmetry of the cerebral hemispheres. In addition, these results strengthen the belief that well-defined neuropsychological tests can be very useful for assessing specific cortical functions and the specific losses produced by missile wounds. Unlike Weinstein and Teuber's (1957a) study using the AGCT, Newcombe's research delineates various components of general intelligence, thus allowing for useful comparisons according to side and locus of injury.

Newcombe, however, is quick to dismiss the utility of general intelligence measures such as the Wechsler Intelligence Scale for detecting the effects of missile wounds on higher-order processes. She clarifies this point by comparing her results (a) above) and those of a pilot study she conducted using the WAIS (Newcombe, 1965, as cited in Newcombe, 1969) with those of Walker and Jablon (1961). Newcombe found no significant differences between experimental subjects and controls in either of her studies. (It should be noted, however, that Newcombe employed only mean scores and overall distributions instead of scale-by-scale comparisons in her work with the WAIS.) In contrast, Walker and Jablon found "general intellectual deterioration" in almost one-fourth of their sample, based on Wechsler-Bellevue IQ scores. Clearly, Walker and Jablon's (1961) conclusions appear to be too hasty. Their deterioration scores were calculated from Wechsler's "deterioration quotient" formula; this is based on an unfounded notion that some subtests are easily affected by brain damage ("don't-hold" subtests) while others are impervious to the same insults ("hold" subtests). Newcombe suggests that such discrepant results illustrate the meaninglessness of terms such as "general intelligence".

Although it is agreed that notions of "general intelligence" neglect the complexity of the human intellect, the present study illustrates that much can be gained through general intelligence tests by analyzing individual subtest scores. The present study was designed similar to Newcombe's; intellectual ability was analyzed in terms of its component subskills. Information regarding intellectual functioning was obtained from the 11 subtests of Wechsler's Intelligence Scales, thereby including measures of both verbal and nonverbal abilities.

It was hypothesized that group comparisons would show the following: (1) Significant subtest score differences based on side and locus of damage. These should reflect impairments in specific intellectual functions, as suggested by Newcombe (1969); and (2) Less impairment on these subtests in younger subjects because of greater abilities for recovery (Hurt & Teuber, as discussed in Teuber, 1975).

Chapter 2

METHODS

SUBJECTS

The subjects for this study were 80 American veterans of World War II, all of whom incurred an open head injury while in combat. These injuries involved the penetration of a bullet or shrapnel through the skull into the brain substance. Each of these men was treated and/or operated upon by Dr. A. Earl Walker (presently affiliated with the University of New Mexico) and later assessed by his team of examiners in a special project studying post-traumatic epilepsy. Some of the data from this pool has been considered in previous research on open head injury (Walker & Erculei, 1968; Walker & Jablon, 1961).

Each subject was known, through personal, family, and hospital reports to have had at least one epileptic attack following his injury. This suggests that the subjects under consideration had sustained quite serious wounds, as discussed in the literature on post-traumatic epilepsy following war wounds (e.g., Caviness, 1969). Previous to their injuries, all of the subjects had been healthy men between the ages of 18 and 33. None were known or suspected of having had epileptic seizures or other neurological abnormalities prior to their wounding.

DATA COLLECTION

Intelligence Measures - Walker and his colleagues conducted a 15-year follow-up (in 1959-60) on the sample of veterans considered in this study. In addition to a full neurological work-up, the subjects were given several psychometric tests and questionnaires to complete. Among the tests administered were the Wechsler-Bellevue and Wechsler Adult Intelligence Scales (both forms were used in the 1960 follow-up, at which time the WAIS was coming into popular clinical use). Scaled scores from these tests were used as the dependent measures of intellectual functioning for the present study.

Side of Injury - The location and extent of each subject's wound had been documented through radiologic and surgical techniques shortly after injury. Table 1 summarizes other clinical characteristics of the subjects. For the purposes of the present study, each subject's injury was recorded as either Right or Left Hemisphere, based on the original medical reports. As others studying subjects with penetrating brain wounds have recommended (e.g., Newcombe, 1969; Semmes, et al., 1960), the true locus of injury should be considered tentative in the absence of verifiable histological evidence. Cases of bilateral damage, including through-and-through wounds of both hemispheres, were excluded from the present study. In addition, because of suspected differences in cerebral organization between right- and left-handed persons (Milner, Branch & Rasmussen, 1964), only right-handed subjects were considered in the present analyses.

Locus of Injury - Wounds were classified according to area or lobe of primary damage. These were coded as either Anterior (frontal,

TABLE 1

Descriptive characteristics of head injured subjects administered the W-B and WAIS, grouped by side and locus of injury

	Wechsler-Bellevue	WAIS
Left Anterior		
	n=10	n=4
Wound location		
Frontal	6	3
Fronto-parietal	4	1
Presence of		
Dysphasia	1	1
Visual defect	0	0
Left Posterior	n=24	n=12
Wound location		
Parietal	14	5
Temporal	1	2
Parieto-temporal	3	1
Occipital	1	1
Parieto-occipital	5	3
Presence of		
Dysphasia	8	4
Visual defect	9	1
Right Anterior	n=6	n=1
Wound location		
Frontal	2	-
Fronto-parietal	3	-
Fronto-temporal	1	1
Presence of		
Dysphasia	0	0
Visual defect	1	1
Right Posterior	n=16	n=8
Wound location		
Parietal	8	7
Temporal	2	-
Parieto-temporal	3	1
Parietal-occipital	3	-
Presence of		
Dysphasia	0	0
Visual defect	6	3

pre-frontal, fronto-temporal, and fronto-parietal wounds) or Posterior (including parietal, temporal, parieto-temporal, occipital, temporo-occipital, and parieto-occipital wounds) in the brain. The decision to employ this rather gross anterior-posterior division was based on (1) the limited number of subjects available, making adequate lobe by lobe comparisons quite difficult, and (2) the general contention that "the conventional anatomical subdivisions of the cerebrum into lobes is an arbitrary one." (McFie, 1969)

Age at Injury - Age at injury was obtained from the original army injury reports for each subject. Age was coded in full number of years at time of injury.

Presence of Dysphasia/Visual Field Defects - In the absence of more objective measures, clinical reports from the follow-up neurological examinations were used to distinguish subjects with residual symptoms of dysphasia and visual field abnormalities. The dysphasic group included cases of both expressive and receptive language impairments. The group with visual field abnormalities included cases of both hemianopsia and quadrantanopsia.

STATISTICAL DESIGN

Comparative studies on the Wechsler-Bellevue and Wechsler Adult Intelligence Scales suggest that they are not statistically equivalent (Fitzhugh & Fitzhugh, 1964), despite the repetition of the same subtests and many of the same items from the W-B to the WAIS. Also, factor analytic studies have proposed that the tests are composed of different underlying elements (Reed & Fitzhugh, 1967). Therefore, the two tests and their respective subtests were considered independently as measures of intellectual functioning.

The Wechsler Scale scores for each subject were coded as scaled scores, including (1) Full Scale IQ, (2) Verbal IQ, (3) Performance IQ, and (4) each of the 11 subtest scores: Information, Comprehension, Arithmetic, Similarities, Digit Span, Vocabulary, Picture Completion, Picture Arrangement, Block Design, Object Assembly, and Digit Symbol. Fixed model two-way multiple analyses of variance were performed on the W-B and WAIS scores separately, with side (right and left) and locus (anterior and posterior) of injury as the independent variables and the 11 subtests as the dependent measures of intellectual functioning. Following this, a series of 14 separate two-way analyses of variance were run for each of intelligence measures, with side and locus of injury as the independent variables. To assess the relationship between the intelligence measures and age at injury, Pearson Product-Moment correlations were computed between each of the 14 Wechsler scaled scores and age at injury for each subject.

To test whether the presence of dysphasic and visual field defects in subjects has an effect on group mean scores, subjects classified as such were excluded from a second set of statistical analyses of the intelligence measures.

All of the statistical analyses were computed with Statistical Analysis System (SAS) computer subprograms. In the case of the MANOVAs and ANOVAs, the factorial designs were unbalanced, involving a different number of subjects per cell. It is assumed that this state of affairs occurred by chance, that "the unequal partitioning of subjects into cells is random ... and in no way related to the nature of treatments (conditions)." (Edwards, 1979, p. 161) Therefore, the most appropriate SAS subprogram was used: A General Linear Models analysis of variance (SAS User's Guide, Statistics, 1982).

HYPOTHESES

It was expected that results similar to Newcombe's (1969) would be found; that is, left hemisphere lesions would result in significantly lower verbal intelligence scores, while right hemisphere lesions would similarly depress scores on measures of visual-spatial, visual-constructional, and other nonverbal skills. In general, no differences were expected to obtain between the two groups on general measures of intellectual functioning (i.e., Wechsler Full Scale IQ scores). Based on other studies which have considered the anatomical correlates of specific intellectual losses, it was expected that lower scores on the individual subtests would depend on the interaction of hemisphere and locus of injury. Also, it was hypothesized that, regardless of site of damage, younger subjects would be more resilient to the effects of brain injury (i.e., show fewer, less severe intellectual deficits) than older subjects.

Chapter III

RESULTS

To assess the effects of open head injury on later intelligence test scores, 2 x 2 MANOVAs were run with side (right vs. left) and locus (anterior vs. posterior) of injury as the independent variables and the 11 subtests of the Wechsler-Bellevue and Wechsler Adult Intelligence Scales as the dependent variables. Using Hotelling-Lawley's Trace criterion, the MANOVA performed on the Wechsler-Bellevue scores yielded marginally significant results for an overall side x locus interaction ($F(11,42)=1.95$, $p < .10$). The tests for the main effects of side ($F(11,42)=1.04$, $p=.43$) and locus of injury ($F(11,42)=$ 70, $p=73$) did not even approach statistical significance. Using this same criterion, the 2 x 2 MANOVA run on the WAIS scores did not yield significant results for either main effect ($F(11,10)=1.02$, $p=.49$ for side of injury; $F(11,10)=.24$, $p=.99$ for locus of injury) or for the side x locus interaction ($F(11,10)=1.09$, $p=.45$).

In addition, a series of 2 x 2 ANOVAs were conducted to study the relationships between the side and locus of injury and each of the 14 measures of intellectual functioning (including Full Scale IQ, Verbal IQ, Performance IQ, and each of the 11 subtest scores). These results are presented below for the W-B and WAIS measures separately. (Summary tables for each of the statistically significant analyses can be found in Appendix B.)

WECHSLER-BELLEVUE SCALE RESULTS

The 14 intelligence measures for the 56 subjects who had been administered the W-B were considered separately in a series of 2 x 2 ANOVAs with side and locus of injury as the independent variables. Means by group for side and locus of injury used in these analyses are listed in Table 2. As can be seen, the only statistically significant main effects for side of lesion were found for the Verbal IQ (F=3.95, $p < .05$), Arithmetic (F=4.38, $p < .05$), Similarities (F=4.70, $p < .05$), and Digit Span (F=4.36, $p < .05$) measures. In each case, the group with right hemisphere lesions obtained higher scores than did those with left hemisphere lesions. Higher, but not statistically significant, mean scaled scores were obtained by the right-hemisphere-injured group on each of the other Verbal subtests, as illustrated in Figure 1. On Performance subtests, the left-hemisphere-lesioned group obtained higher mean scores on only two subtests: Picture Completion and Object Assembly.

No significant main effects for locus of lesion were found on any of the 14 measures. However, higher, though not significant, scores were obtained on almost all of the W-B measures by the anterior-lesioned group.

Means by cell for each of the intellectual measures are listed in Table 3. Several side x locus interactions reached statistical significance. These were found in the Arithmetic (F=5.83, $p < .05$), Block Design (F=8.30, $p < .01$), and Digit Symbol (F=7.28, $p < .01$) analyses. These interactions are represented graphically in Figure 2 - 4. Using the Newman-Keuls test for simple effects within the

TABLE 2

Side and locus of injury mean score comparisons among W-B Scales

	Left (n=34)	Right (n=22)	Ant. (n=16)	Post. (n=40)
FSIQ	103.24	109.36	106.94	105.13
VIQ	98.76*	109.50	105.00	102.17
PIQ	107.71	108.73	108.31	108.02
Info.	10.50	11.77	11.38	10.85
Comp.	9.74	11.22	10.44	10.28
Arith.	7.26*	9.41	8.62	7.90
Simil.	9.71*	11.50	10.25	10.48
Dig. Sp.	6.74*	9.55	9.06	7.35
Vocab.	9.18	10.46	9.88	9.60
P. Comp.	11.00	11.59	10.88	11.38
P. Arr.	10.00	9.32	9.88	9.68
Bl. Des.	9.53	9.82	10.25	9.40
Ob. As.	10.29	9.96	9.81	10.30
Dig. Sy.	6.79	7.77	8.06	6.82

* $p < .05$

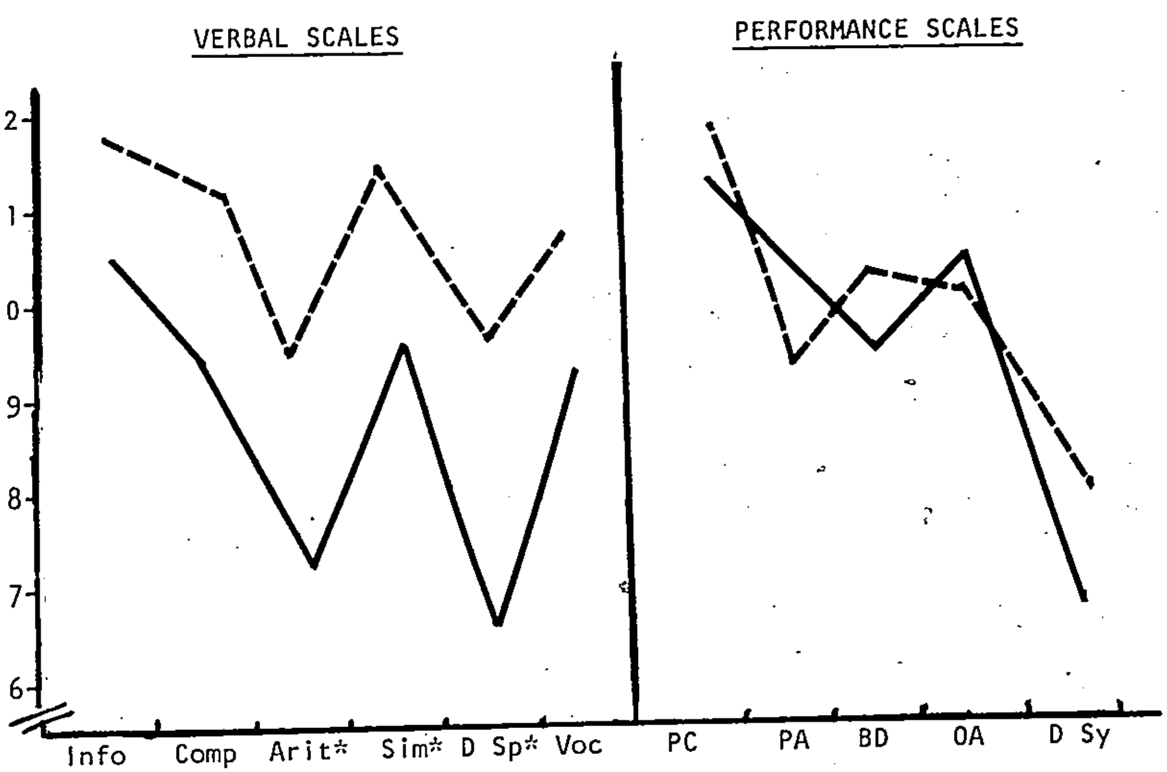

Figure 1. Left Hemisphere Vs. Right Hemisphere Differences in W-B Mean Scaled Scores

= Left Hemisphere damage = Right hemisphere damage
* = difference significant at p ∠ .05

TABLE 3

Wechsler-Bellevue scaled score means by cell used in MANOVA and ANOVA procedures

	Left-Ant.	Left-Post.	Right-Ant.	Right-Post.
FSIQ	107.8	101.3	105.5	110.8
VIQ	103.7	96.7	107.2	110.4
PIQ	111.2	106.2	103.5	110.7
Info.	11.5	10.1	11.2	12.0
Comp.	9.8	9.7	11.5	11.1
Arith.*	9.3	6.4	7.5	10.1
Simil.	9.4	9.8	11.7	11.4
Dig. Sp.	8.7	5.9	9.7	9.5
Vocab.	9.8	8.9	10.0	10.6
P. Comp.	10.8	11.0	11.0	11.8
P. Arr.	10.1	10.0	9.5	9.2
Bl. Des.**	11.4	8.8	8.3	10.4
Ob. As.	10.5	10.2	8.7	10.4
Dig. Sy.**	8.8	6.0	6.8	8.1

*$p < .05$ for interaction
** $p < .01$ for interaction

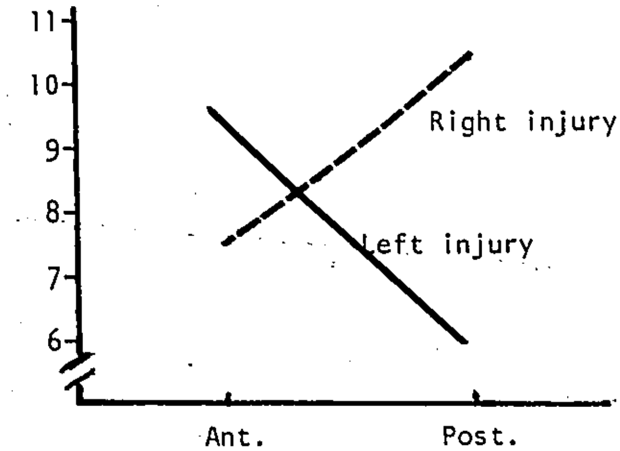

Figure 2. Interaction Between Side and Locus of Injury for Arithmetic Subtest Scores

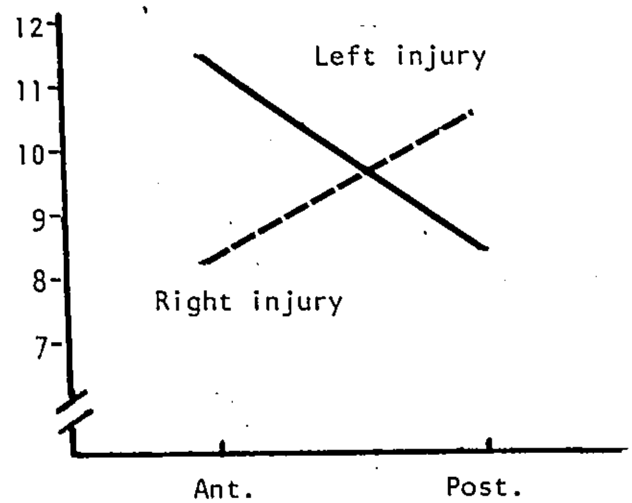

Figure 3. Interaction Between Side and Locus of Injury for Block Design Subtest Scores

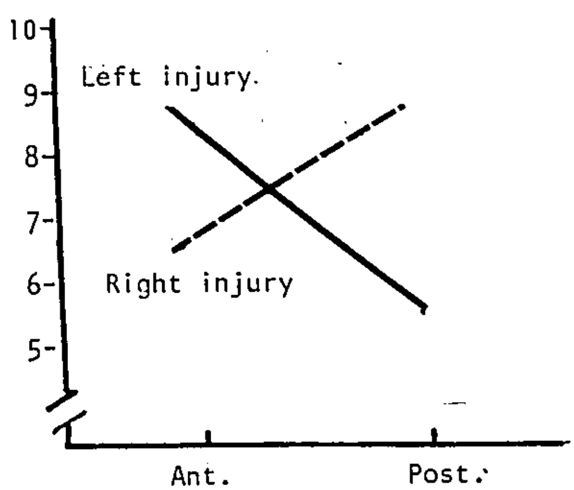

Figure 4. Interaction Between Side and Locus of Injury for Digit Symbol Subtest Scores

interaction, it was found that the Arithmetic subtest interaction showed significant differences between the left-posterior and right-posterior groups ($p < .05$). The interaction for Block Design showed significant differences between the left-anterior and right-anterior groups, while the significant difference in the Digit Symbol interaction occurred between the left-anterior and left-posterior groups.

To better illustrate the trends occurring between side and locus of injury on the intelligence measures, the groups themselves have been listed in Table 4 in ascending order of mean scores. From a quick glance, it is quite apparent that the left-posterior-lesioned group fared poorest overall. This group most frequently obtained the lowest or second-lowest subtest scores in comparison to the other groups. Next in terms of impairment seems to be the right-anterior group, followed by the left-anterior and right-posterior groups.

After excluding subjects who showed dysphasic symptoms, these same statistical analyses were carried out with the W-B scores. Using Hotelling-Lawley's Trace criterion, the 2 x 2 MANOVA yielded results approach~~ing~~ statistical significance for the side x locus interaction ($F(11,33)=1.77$, $p < .10$).

No main effects for side or locus of injury were found to be significant for any of the 14 intelligence measures. Nonetheless, the left hemisphere group means remained lower than the right hemisphere means on each of the Verbal subtests. A side x locus interaction was found to be significant for the Digit Symbol analysis ($F=6.58$, $p < .05$), with appreciable differences occurring between the left anterior and left-posterior groups.

TABLE 4

Rank-order listing of groups by lesion site from lowest to highest mean scores on W-B measures

	1 (Lowest)	2	3	4 (Highest)
FSIQ	L-P	R-A	L-A	R-P
Info.	L-P	R-A	L-A	R-P
Arith.	L-P	R-A	L-A	R-P
Dig. Sy.	L-P	R-A	R-P	L-A
VIQ	L-P	L-A	R-A	R-P
Vocab.	L-P	L-A	R-A	R-P
Comp.	L-P	L-A	R-P	R-A
Dig. Sp.	L-P	L-A	R-P	R-A
Simil.	L-A	L-P	R-P	R-A
P. Comp.	L-A	L-P*	R-A*	R-P
PIQ	R-A	L-P	R-P	L-A
Bl. Des.	R-A	L-P	R-P	L-A
Ob. As.	R-A	L-P	R-P	L-A
P. Arr.	R-P	R-A	L-P	L-A

N.B. - Subtests are arranged according to trend similarities

L-P = Left Posterior
L-A = Left Anterior
R-A = Right Anterior
R-P = Right Posterior

* denotes tied scaled scores

In similar fashion, those subjects who evidenced visual field defects were excluded from the analyses systematically. This MANOVA resulted in a clearly significant F value for the overall side x locus interaction ($F(11,26)=2.92$, $p \angle .05$). Statistically significant main effects for side of lesion were obtained in the VIQ ($F=4.60$, $p \angle .05$), Comprehension ($F=4.20$, $p \angle .05$), Similarities ($F=6.26$, $p \angle .05$), and Digit Span ($F=3.26$, $p \angle .10$) ANOVAs. Side x locus interactions similar to those obtained with the inclusion of visual field-impaired subjects were found in the Arithmetic ($F=5.49$, $p \angle .05$), Block Design ($F=8.64$, $p \angle .01$), and Digit Symbol ($F=3.37$, $p \angle .10$) analyses.

WECHSLER ADULT INTELLIGENCE SCALE RESULTS

Considering only the 24 subjects who had been administered the WAIS, very few of the individual 2 x 2 ANOVAs yielded significant results. Means for the side and locus of injury groups used in the individual ANOVAs are listed in Table 5. Main effects for the side variable approached significance ($p \angle .10$) in the Similarities ($F=3.20$) and Object Assembly ($F=4.30$) analyses. As illustrated in Figure 5, it was found that higher, but not statistically significant, means scores were obtained by the right-hemisphere-lesioned group on each of the Verbal scales except Digit Span, while the left hemisphere group obtained higher scores on each of the Performance subtests.

No main effects for locus of lesion were found to be statistically significant. Nonetheless, the anterior-lesioned group obtained higher scores than the posterior-lesioned group on 12 of the 14 intelligence measures. Tests for side x locus interactions could not be

TABLE 5

Side and locus of injury group mean score comparisons among Wechsler Adult Intelligence Scales

	SIDE		LOCUS	
	Left (n=15)	Right (n=9)	Ant. (n=4)	Post. (n=20)
FSIQ	101.93	102.56	105.25	101.55
VIQ	99.80	107.00	103.50	102.30
PIQ	104.60	96.56	107.00	100.50
Info.	11.00	12.11	11.75	11.15
Comp.	10.80	12.00	11.75	11.15
Arith.	10.47	11.00	10.75	10.65
Simil.*	10.20	12.11	9.50	11.20
Dig. Sp.	8.80	8.78	9.25	8.70
Vocab.	9.27	10.89	10.00	9.85
P. Comp.	10.60	9.89	10.00	10.40
P. Arr.	9.47	8.67	10.00	9.00
Bl. Des.	10.53	8.67	10.50	9.70
Ob. As.*	10.80	8.67	11.75	9.65
Dig. Sy.	7.93	6.89	8.00	7.45

* $p < .10$

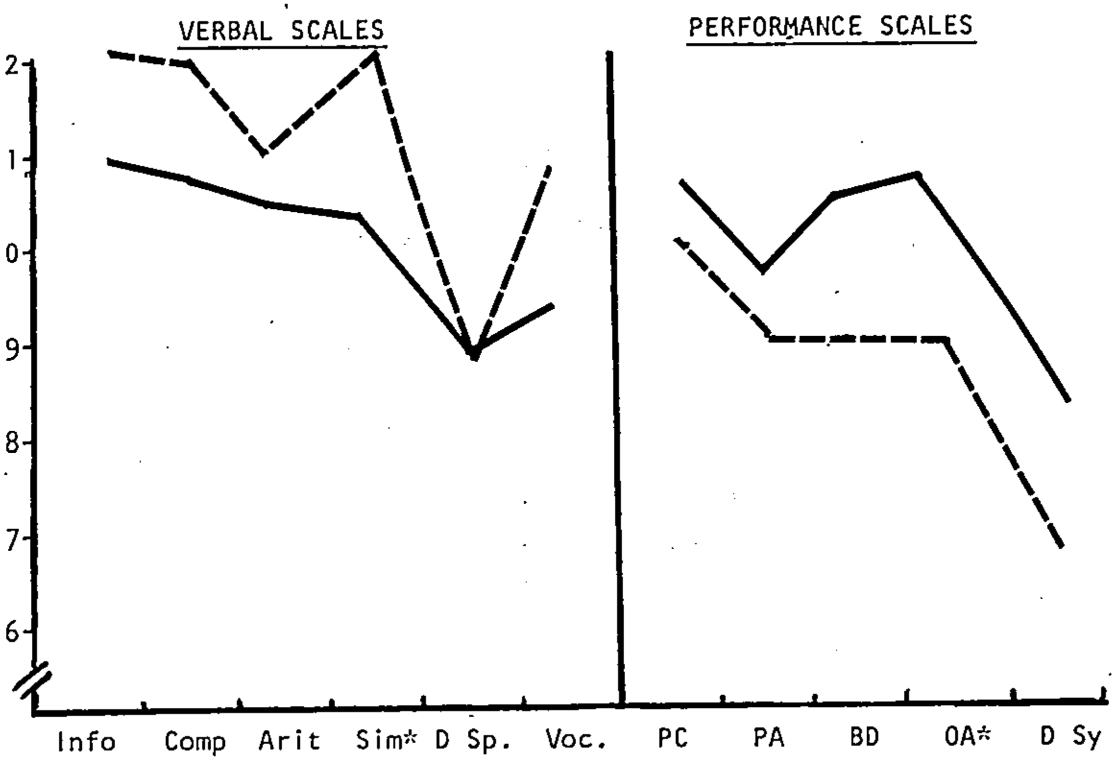

Figure 5. Left Hemisphere Vs. Right Hemisphere Differences in Mean WAIS Scaled Scores

——— = Left hemisphere damage — — — = Right hemisphere damage
* = difference significant at $p < .10$

considered statistically meaningful because of the limited number of subjects in some cells.

The exclusion of clinically-determined dysphasic subjects from the analyses resulted in essentially little change from the results obtained with their inclusion. Only one main effect for side of lesion was found to reach statistical significance; this was obtained in the ANOVA run with Object Assembly scores (F=6.13, $p < .05$).

Following the exclusion of subjects who displayed visual field abnormalities, the statistical tests were again repeated. The 2 x 2 multiple analysis of variance was now found to approach significance for an overall side effect ($F(11,6)$=3.20, $p < .10$). The individual ANOVAs resulted in no significant main effects for locus of lesion and only one marginally significant main effect for side of injury. This was found in the ANOVA performed with Similarities subtest scores (F=4.07, $p < .10$).

INTELLIGENCE MEASURES AND AGE

To study the relationships between age at injury and residual intellectual abilities, as measured by the W-B and WAIS, a series of Pearson Product-Moment correlations were computed. Correlation coefficients for each of the 14 measures of both the Wechsler-Bellevue and Wechsler Adult Intelligence Scales are presented in Table 6.

For the W-B group, the only correlation to reach statistical significance was found between age and Picture Completion subtest scores (r=.26, $p < .05$). Correlations with Full Scale IQ (r=.25), Verbal IQ (r=.24), Information (r=.25), and Comprehension (r=.23) scaled

TABLE 6

Pearson product-moment correlation coefficients between age at injury and W-B, WAIS scaled scores

	W-B Scores and Age	WAIS Scores and Age
FSIQ	.250*	.166
VIQ	.240*	.310
PIQ	.200	-.070
Info.	.255*	.227
Comp.	.228*	.240
Arith.	.102	.100
Simil.	.167	.448**
Dig. Sp.	.096	.160
Vocab.	.206	.312
P. Comp.	.265**	-.171
P. Arr.	-.047	-.128
Bl. Des.	.087	-.343*
Ob. As.	-.132	-.135
Dig. Sy.	-.021	.057

* $p < .10$

** $p < .05$

scores were found to be marginally significant ($p < .10$).

The only correlation between age at injury and WAIS scaled scores that reached significance was found with Similarities ($r=.45$, $p < .05$) subtest scores. A negative correlation between age and Block Design scores ($r=-.34$, $p=.10$) also approached the level of significance.

Chapter IV

DISCUSSION

RIGHT VS. LEFT HEMISPHERE INJURY

In general, the present results support the hypothesis that right and left hemisphere injuries have differential effects on residual intellectual abilities. As expected, based on other open head injury studies, no differences were found between right and left-hemisphere-lesioned groups on general measures of intellectual functioning (Full Scale IQ) for either the W-B ($\bar{X}$=103.24 for left hemisphere cases; $\bar{X}$=109.36 for right hemisphere cases) or WAIS ($\bar{X}$=105.25 for left hemisphere cases; $\bar{X}$=101.55 for right hemisphere cases).

However, differences in Verbal and Performance IQ were in evidence. Comparisons between the right and left hemisphere injury groups and anterior and posterior locus of lesion groups are illustrated in Figures 6 to 11, based on the W-B, WAIS, and combined W-B and WAIS results, respectively. (Figures 10 and 11 are shown merely to illustrate the advantage of a larger sample size; interpretations of these graphs should be made with caution in light of studies suggesting that the W-B and WAIS are not statistically similar [Fitzhugh & Fitzhugh, 1964].)

As can be seen, in each case the right-injured group obtained higher VIQ scores than the left-injured group. Conversely, the left-injured group obtained higher PIQ scores than the right-injured group

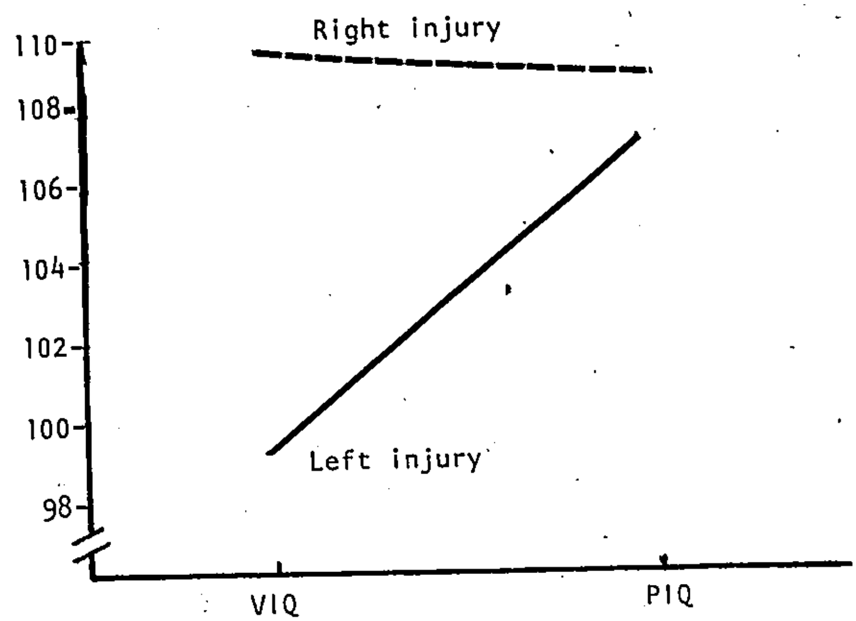

Figure 6. Wechsler-Bellevue VIQ - PIQ Differences Along Side of Injury Variable

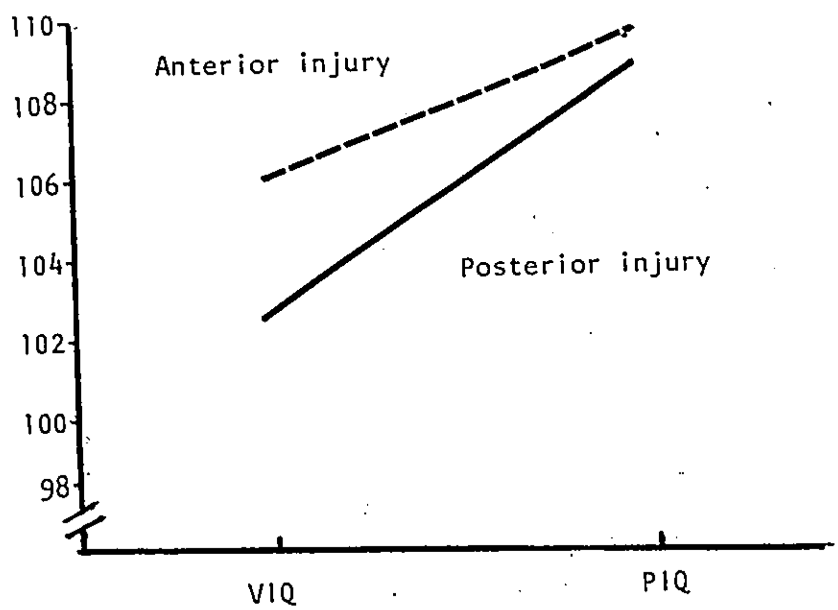

Figure 7. Wechsler-Bellevue VIQ - PIQ Differences Along Locus of Injury Variable

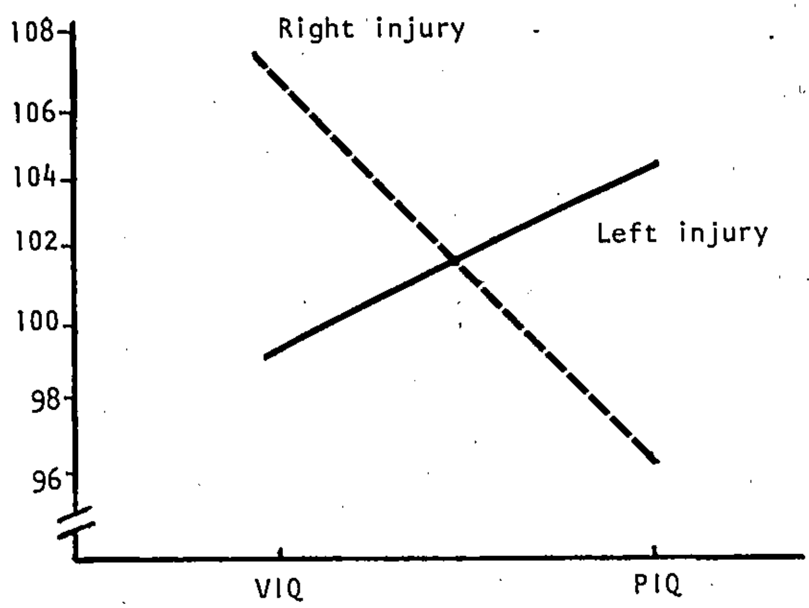

Figure 8. Wechsler Adult Intelligence Scale VIQ - PIQ Differences Along Side of Injury Variable

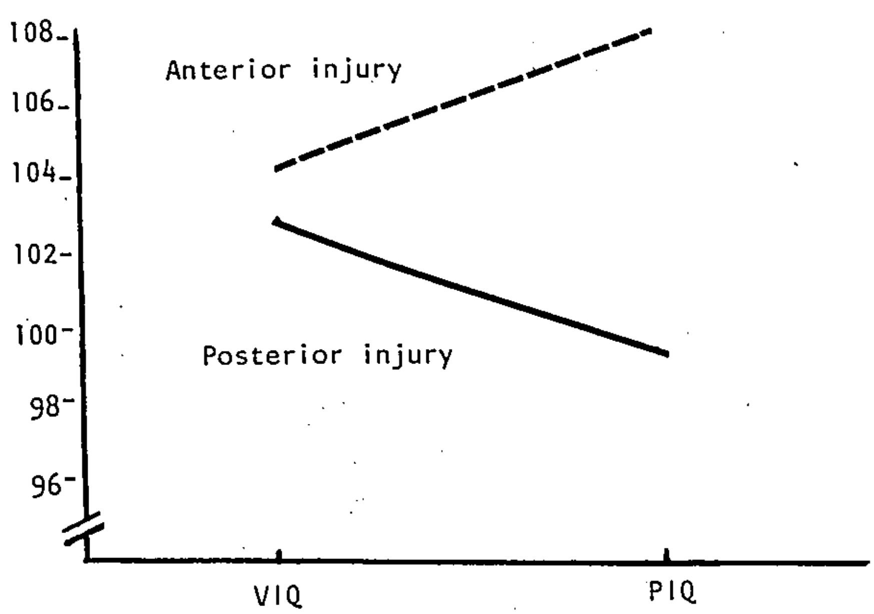

Figure 9. Wechsler Adult Intelligence Scale VIQ - PIQ Differences Along Locus of Injury Variables.

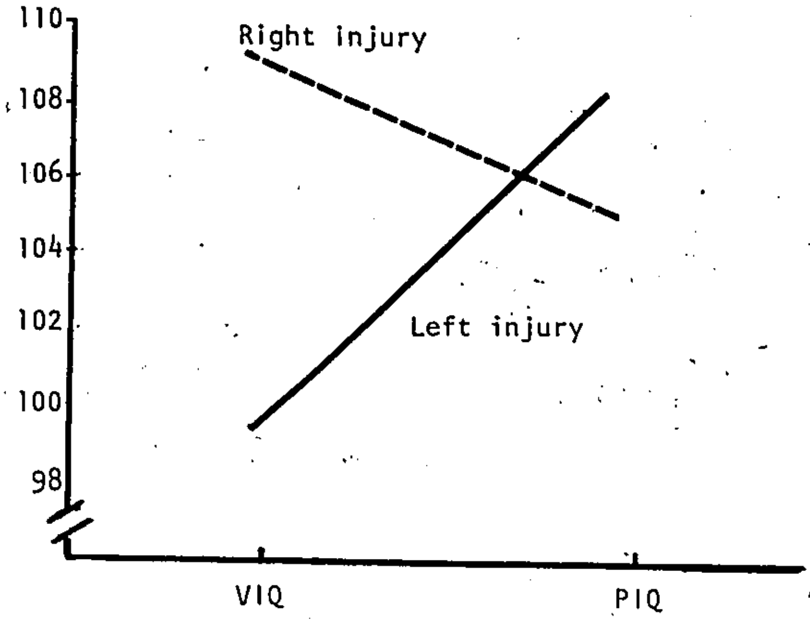

Figure 10. Combined W-B and WAIS VIQ - PIQ Differences Along Side of Injury Variable

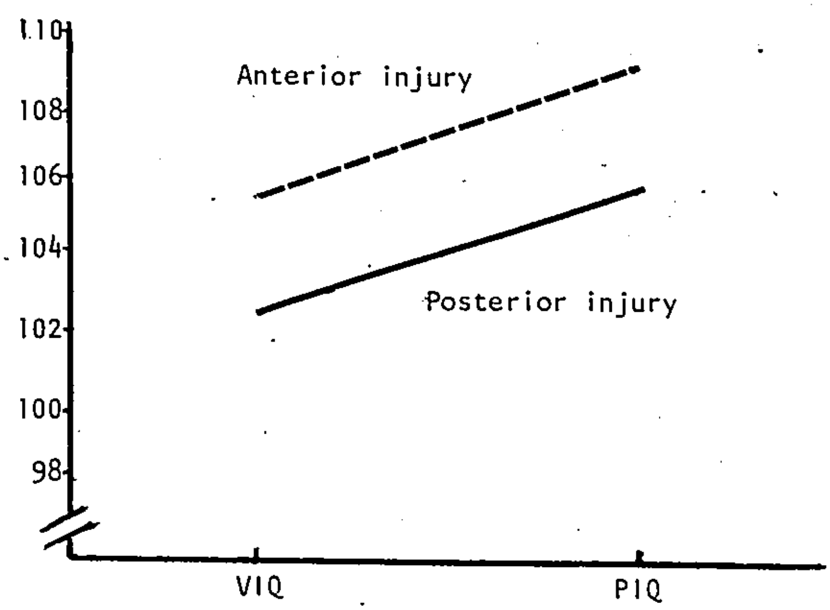

Figure 11. Combined W-B and WAIS VIQ - PIQ Differences Along Locus of Injury Variable

using means from the WAIS and combined W-B and WAIS. The results reflected in Figure 10 are most consistent with the results of other studies (Meyer & Jones, 1957; Heilbrun, 1956 - as discussed in Benton, 1962) in which right-left hemisphere injury differences were found to be greater along verbal measures than along spatial measures. The implications that such results have on a general theory of cerebral organization will be discussed in detail in a later section.

The finding that the Verbal subtests showed greater right-left differences than the Performance subtests may be attributed to the fact that the majority of the subjects in this study were lower-ranking men in the army selected for front-line duty. In addition, many of them did not have the benefit of much formal education; less than half of them had finished high school. These subjects might, therefore, represent a group with a typical profile of below or low-average pre-injury verbal abilities, while their nonverbal "performance-type" abilities were above-average prior to their injuries. The left hemisphere group's scores on verbal scales would then be spuriously low, while the right hemisphere group's deficits among Performance subtests would be underestimated. Unfortunately, pre-injury intelligence test scores were unavailable for these subjects for purposes of pre- and post-injury comparison.

Although only 5 of the 14 W-B measures of intelligence resulted in statistically significant main effects for side of lesion on the individual ANOVA tests, the means for each of the Verbal subtests were lower for the left-hemisphere-lesioned group. The opposite was found on 2 of the 5 Performance subtests: right-hemisphere-lesioned subjects obtained lower mean scores. These effects were even more consistent, despite the lack of statistical significance, in the WAIS analyses. Left-hemisphere-lesioned subjects obtained lower or equivalent scores on all Verbal subtests while the right-hemisphere-injured group obtained lower scores on all Performance subtests. These results are illustrated in Figure 1 and 5. Such findings are similar to those obtained by Reitan (1955) in an early study with the Wechsler-Bellevue Scales.

Comparing the results of this study to those of Newcombe (1969) in which she used some of the WAIS subtests as measures of intellectual functioning, one finds many similarities. Although she found that subjects with right anterior lesions fared worst on the Similarities subtest and the present study resulted in a clear right hemisphere group advantage, Similarities was found to be one of the few subtests in which the anterior-lesioned subject group scored more poorly than the posterior group. Newcombe interpreted her finding as an inability of right anterior-lesioned subjects to "shift set". Also similar to the present results, Newcombe found lower (though not statistically significant) scores for the left-hemisphere-injured group on the Arithmetic subtest of the WAIS. (This effect reached statistical significance with the W-B results in the present analysis.)

Newcombe's findings were also replicated with the Digit Span and Block Design subtest analyses. In the case of Digit Span, significantly lower scores were obtained by subjects with injuries to the left hemisphere. For the Block Design subtest, the right-hemisphere-lesioned group performed more poorly than the left-lesioned group. It appears, in fact, that the Wechsler subtests which Newcombe chose to use in her study -- Similarities, Arithmetic, Digit Span, and Block Design, with the addition of Object Assembly -- were indeed the most discriminating tests between cases of right and left hemisphere injury on the W-B and WAIS. It is hypothesized that other Verbal and Performance subtests might well show right-left hemisphere injury differences if pre-injury scores were available to show the differential declines in score following open head injury.

There may be some reasons for the increased sensitivity of these subtests over others to the effects of penetrating brain injury. The very nature of the Similarities, Arithmetic, and Digit Span subtests -- in which nonredundant complex verbal information is presented to the subject and he is asked to utilize it in a novel way -- may account for the greater likelihood of difficulty for subjects with left hemisphere injury. Even slight impairments in the language system might disrupt the ability to deal with the complex verbal abilities and attentional abilities required by these subtests. These subtests stand in contrast to other Verbal subtests, such as Information and Vocabulary, which rely on overlearned verbal information and skills.

In the case of poor right-hemisphere-group scores on the Block Design and Object Assembly subtests, these may be attributed to the heavy reliance of these subtests on "pure" visual-spatial and visual-constructional skills generally considered to be subserved more exclusively by the right hemisphere. The other Performance subtests, such as Picture Completion and Picture Arrangement, may be relatively impervious to such insults because they tend to require problem-solving and verbal abilities as well as visual-spatial skills. That is, for those subtests which are dependent less exclusively on visual-spatial skills than Block Design and Object Assembly, damage to right hemisphere visual-spatial function may not impair overall performance as significantly.

ANTERIOR VS. POSTERIOR LESION DIFFERENCES

The lack of clear-cut findings concerning the locus (anterior or posterior) of injury in the brain may well attest simply to the arbitrary nature of making such divisions of the cerebral cortex. Although the anterior-lesioned group tended to obtain higher scores on most of the W-B and WAIS subtests and measures of general Verbal IQ and Performance IQ (as illustrated in Figures 7, 9, and 11), none of these differences reached commonly accepted levels of statistical significance. The pattern of differences also varied greatly, depending on the intelligence test used.

On the W-B, the posterior-lesioned group fared better on only the Similarities, Picture Completion and Object Assembly subtests; on the WAIS, this was true only for the Similarities and Picture Completions subtests. This perhaps indicates that these two subtests are sensitive to some ability subserved by anterior regions of the brain. A common requirement of these tests is the ability to find appropriate words spontaneously, thus lending support to the notion that word-finding ability is associated with frontal (primary left) cortical regions. These consistent inter-test findings would also appear to constitute a type of "cross-validation" between the Wechsler-Bellevue and WAIS Similarities and Picture Completion subtests for measuring similar abilities.

The lack of other low scores for the anterior-lesioned group stands in marked contrast to early findings which held that intellectual impairment is greatest following damage to the frontal lobes (e.g., Rylander, 1939; Shure & Halstead, 1958). Also, the finding that anterior-lesioned subjects were relatively unimpaired on quite demanding subtests such as Arithmetic, Digit Span, and Digit Symbol contradicts Luria's (1974) contention that frontal lobe dysfunction is characterized by a disturbance in attention and concentration and an inability to perform complex actions in sequence.

The many lower scores obtained by the posterior group likely reflect damage to important primary and secondary sensory centres and the language processing systems subserved by the left parietal and temporal lobes. Had a sufficient number of subjects been available, lobe by lobe comparisons such as utilized by Newcombe (1969) might have shown more outstanding anterior-posterior differences. The trend toward left-posterior-lesioned subjects faring worst on the majority of the measures could then be explored in more detail, distinguishing, for example, between the effects of left temporal, parietal, and occipital lesions. In general, the finding that left posterior subjects fared the worst overall is consistent with other reports on the Wechsler subtests (McFie, 1960 as discussed in McFie, 1969).

DYSPHASIA AND VISUAL FIELD DEFECT EFFECTS

The exclusion of dysphasic subjects from the W-B and WAIS analyses altered group mean scores sufficiently so as to minimize the right and left hemisphere injury differences. That is, the Verbal subtests which resulted in significantly lower mean scores for the left hemisphere group (Similarities, Arithmetic, and Digit Span) were no longer statistically significant with the exclusion of language-impaired subjects. It appears that these subjects' markedly low scores were responsible for depressing the group means substantially. The only right-left difference which remained statistically significant was found on the WAIS Object Assembly subtest.

These results are in line with those of Newcombe who found that dysphasic subjects were more impaired than normals, right hemisphere and non-dysphasic left-hemisphere-injured subjects on almost all verbal tasks, but performed normally on nonverbal tasks. Similarly, Weinstein and Teuber (1957a) found that left hemisphere brain wounds, specifically those resulting in clinical symptoms of dysphasia, were associated with the most impairment on a verbal measure of general intelligence.

Nonetheless, it is quite difficult from the present analyses to draw conclusions concerning the relationship between dysphasia and intellectual abilities. This is due, in part, to the lack of clear and specific criteria for determining the language impairment. In the present study, for example, subjects were considered to be dysphasic on the basis of subjective clinical reports by neurologists who had assessed the subjects' abilities to speak, write, and understand everyday language. In addition, the relationship between dysphasia and intellectual functioning as measured by the Wechsler Scales is unclear because of the test criteria themselves. For example, a dysphasic subject might have obtained a low scaled score on the Arithmetic subtest because he did not answer questions, because he responded inappropriately, because his arithmetical calculations were faulty, or because he misinterpreted the initial question. Whether defects on such measures are due to poor language functioning (per se) or to poor "general intellectual" functioning is difficult, if not impossible, to ascertain with criteria that overlook the qualitative aspects of language functioning.

The exclusion of subjects evidencing visual field defects, in contrast, resulted in fewer changes in group mean scores. The Verbal subtest right-left differences (on Arithmetic, Similarities, and Digit Span for the W-B, on Similarities for the WAIS) remained statistically significant. The only change was that the Object Assembly analysis no longer resulted in a statistically significant main effect for side of lesion; no longer did the left-lesioned group score significantly better than the right-lesioned group. The failure to show differences on other visual-spatial and visual-constructional measures would appear to support Newcombe's contention that, "The balance of evidence, therefore, inclines to the view that field defects per se are not a significant factor in impaired performance on visual-perceptual tasks." (1969, p. 103).

AGE AT INJURY AND INTELLECTUAL ABILITIES

The results of the present study failed to support the hypothesis that age at injury and performance on measures of intelligence are inversely related, such that subjects younger at time of injury show fewer intellectual impairments because of greater brain "resiliency" (Teuber, 1975).

The low positive correlations found to be statistically significant suggest that advanced age at injury is related, albeit only mildly, to better scores on the intelligence measures. This is likely related to the advantages which more schooling, more general experience and knowledge of the world give an individual on such general measures of intellectual functioning. The lack of significance may well also be related to the limited age range of the sample studied (range 18 -33 at time of injury) which would reduce the probability that correlational analyses will produce significant results. Also, years of previous (to injury) and subsequent (until the 15-year follow-up) education had not been properly controlled for.

Although Hurt and Teuber's study (as cited in Teuber, 1975) would suggest that differences in recovery ability exist even within this limited age range, it should be kept in mind that their study was based solely on indices of improvement between the acute and chronic phases of brain injury. Their explanation that older brains are less "resilient" relates only to the degree of functional change occurring over time. The present study was based, in contrast, on residual intellectual abilities during the chronic phase of brain injury; no consideration was given to improvement in these abilities over time. Were post-injury scores available at, for example, 1 and 15 years, comparisons might be made to address the issue of brain "plasticity" in younger versus older subjects. However, it should also be kept in mind that intellectual abilities may rely on a number of different brain centres, any of which might compensate for another in the event of brain injury (Luria, 1963).

W-B VS. WAIS MEASURES

The present findings suggest that very few of the Wechsler Scale subtests reflect statistically significant differences in groups of open head injured subjects. This may be due to either (a) the insensitivity of the measures themselves, or (b) the amount of functional recovery which has occurred in the 15-year interval between wounding and follow-up. The findings from Newcombe's (1969) study, involving the analysis of measures taken 20 years after injury, however, would seem to be inconsistent with this latter hypothesis. When she had compared subjects on the basis of side and lobe of damage, her measures detected many differences in intellectual functioning.

The present study, inasmuch as it demonstrates the relative insensitivity of many of the Wechsler subtests to the effects of open head injury, also raises the question as to which of these tests is more sensitive to the intellectual changes resulting from brain injury. The evidence, as presented here, would tend to favor the W-B, in which 4 of the measures reached statistical significance for the side of injury main effect and 3 measures resulted in significant side x locus interactions. In contrast, however, the WAIS mean scores for right and left-hemisphere-injured groups, though not statistically different, showed a more consistent pattern than the W-B means. (This can be seen by comparing Figures 1 and 5.) In each case, the group with left hemisphere lesions obtained lower WAIS Verbal subtest scores while the right-lesioned group obtained lower Performance subtest scores. From the present data, the small number of subjects assessed with the WAIS makes it quite difficult to compare the W-B statistics with those of the WAIS. If sufficient data were available on cases of open head injury (as perhaps has been done with Vietnam War veterans), a useful comparison between these two scales might be carried out.

CONCLUSIONS

The present study found differences to exist when cases of right hemisphere injury were compared with left hemisphere injury, with Performance tasks impaired in the former and Verbal tasks impaired in the latter. The variables of locus of injury and age at injury were not found to be related in any significant, consistent manner with scores on the various Wechsler Scale measures of intelligence. The exclusion of subjects showing dysphasic symptoms resulted in a loss of statistical significance for some of the Verbal subtest differences, although the left hemisphere-lesioned group still obtained lower mean scores on these measures. In general, it appears that the serious language impairments accounted for the very depressed left hemisphere group scores on Verbal scales. In contrast, the exclusion of subjects with visual field abnormalities resulted in little change of the right and left hemisphere group mean scores on any of the measures.

Although these results point out the inadequacy of general measures of intelligence, such as Full Scale IQ, for detecting between-group differences in the case of open head injury, they do illustrate the utility which some of the individual subtests may have for the same purpose. In particular, the Similarities, Arithmetic, and Digit Span subtests of the Wechsler-Bellevue Scales were found to discriminate between right and left-hemisphere-injury groups. With the limited sample size, only Similarities and Object Assembly resulted in right-left-lesion differences on the Wechsler Adult Intelligence Scale, although it is proposed that other subtests might discriminate as well, given a larger sample size.

These subtest differences might prove to be all the more striking if compared to an age-matched normal control group. Other variables which had not been accounted for that might also prove to be of interest include size and depth of lesion and measures concerning the severity of post-injury coma, infection, and epileptic attacks.

This evidence supports the myriad of studies on both open head injury and on other types of brain insult or disease which have shown that the right and left hemispheres are specified in terms of intellectual function, with language-related functions depending on intact left hemisphere centres and visual-spatial and constructional functions depending on right hemisphere sytems (e.g., Heilbrun, 1969; McFie, 1975). The "double dissociation" of functions reported by Newcombe was not as apparent from the present results, due, in part, to the fact that some of the Wechsler subtests were not as discrete in terms of functions tapped, as were Newcombe's measures. But still her results are mirrored: While the two hemispheres were found to differ in terms of specialized skills and related impairments, the lateralization of verbal functions to the left hemisphere shows a clearer relationship than the lateralization of visual-perceptual and other nonverbal abilities to the right hemisphere.

This same pattern of results has been obtained in a variety of studies suggesting that the right hemisphere is more diffusely organized than the left hemisphere. This has been reported on both basic levels of sensory processing (Semmes, et al., 1960) and on more complex levels of intellectual behaviour. Recently, for example, Kertesz and Dobrowolski (1981) have found that constructional apraxia, impaired visual-spatial problem-solving, and spatial neglect are related to right hemisphere lesions, but that these disturbances can occur with a variety of lesion sites, in contrast to the findings that "well recognized clinical syndromes are clearly related to certain regions in the left hemisphere." (p. 297)

Although the present findings support the notion that multi-scale measures of psychometric intelligence such as Wechsler's may be rather sensitive for detecting the effects of brain injury (particularly on verbal functions), the complexity of the human intellect clearly warrants more precise measures such as have been developed in recent years in the field of neuropsychology. To study the relationships between brain systems and behaviour, this area of endeavor requires well-designed tests in which a complex intellectual subskill such as arithmetic ability is partitioned into its component parts and compared in cases of highly localized brain insult. According to Luria, "In order to provide a correct evaluation of a symptom and its local significance it is only necessary to carry out a qualitative analysis of the structure of the symptom .... Such evaluation of the symptom is the fundamental task of neuropsychology." (1969, p. 9)

In all of this, the hopeful conclusion that can be drawn from such studies is the amazing ability of the human brain to recover functionally from the damaging effects of war wounds. Years after injury, the majority of the subjects studied, despite intellectual deficits, went on to lead useful, productive lives.

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Appendix A

RAW DATA

WECHSLER-BELLEVUE SCORES

Subj.	Side	Loc	Dys	Vis	Age	FIQ	VIQ	PIQ	Inf	Com	Art	Sim	DSp	Voc	PCo	PAr	BID	ObA	DSy
1	L	A	0	0	19	122	116	130	14	15	10	12	9	13	14	15	16	14	10
2	L	A	0	0	29	111	99	122	10	9	9	7	9	10	10	8	12	12	16
3	L	A	0	0	21	103	105	98	12	11	9	9	9	9	7	9	8	10	7
4	L	A	0	0	20	106	102	110	11	8	7	10	11	8	13	11	12	9	6
5	L	A	1	0	23	98	89	107	12	6	7	8	3	9	12	11	11	7	7
6	L	A	0	0	23	117	113	121	13	11	10	13	10	12	15	8	10	12	15
7	L	A	0	0	19	102	98	104	10	9	9	8	9	8	7	11	12	13	6
8	L	A	0	0	25	119	118	118	13	12	13	12	11	12	12	12	13	10	8
9	L	A	0	0	27	113	111	113	13	11	10	10	10	12	10	10	12	12	7
10	L	A	0	0	21	87	86	89	7	6	9	5	6	5	8	6	8	6	6
11	L	P	0	1	20	81	71	93	7	5	1	5	4	4	6	10	6	10	5
12	L	P	0	0	27	103	101	105	8	9	7	10	11	8	13	9	9	8	5
13	L	P	0	0	22	104	101	107	10	10	7	10	9	8	14	6	8	12	8
14	L	P	1	1	21	71	56	92	3	2	0	2	0	4	9	11	7	5	4
15	L	P	1	0	31	112	103	120	13	12	9	9	3	13	13	9	10	13	9
16	L	P	1	0	19	107	89	125	10	11	3	9	2	10	15	14	13	12	7
17	L	P	0	1	25	111	104	117	10	15	4	13	6	11	14	11	12	12	5
18	L	P	1	0	26	107	101	113	11	8	10	7	9	6	12	13	9	11	6
19	L	P	1	0	31	108	103	114	11	11	4	10	10	9	13	12	10	9	5
20	L	P	0	1	21	86	81	92	6	5	6	8	4	6	7	8	6	10	5
21	L	P	1	0	24	105	105	105	10	12	10	11	6	9	13	11	8	5	7

Subj.	Side	Loc	Dys	Vis	Age	FIQ	VIQ	PIQ	Inf	Com	Art	Sim	DSp	Voc	PCo	PAr	BID	ObA	DSy
22	L	P	0	0	31	108	103	114	10	13	9	11	3	9	14	10	10	10	5
23	L	P	0	0	23	100	103	96	9	10	9	11	9	9	9	8	5	10	7
24	L	P	0	0	18	92	93	92	9	11	7	12	2	10	7	11	5	10	6
25	L	P	0	1	24	115	120	107	13	8	13	13	16	13	12	8	12	9	7
26	L	P	0	1	23	112	105	118	15	11	6	14	4	14	13	12	11	13	8
27	L	P	0	0	27	109	97	122	13	10	10	8	0	8	13	14	13	12	6
28	L	P	1	1	30	102	92	113	12	12	0	13	0	10	[illegible]	7	13	12	5
29	L	P	0	1	22	87	88	87	10	6	7	8	4	5	4	6	7	10	5
30	L	P	0	0	22	97	88	105	8	10	3	10	4	8	13	11	8	11	4
31	L	P	0	0	20	97	99	94	10	11	6	9	9	9	10	7	6	10	5
32	L	P	0	1	25	116	128	102	15	14	12	16	13	14	8	7	8	10	8
33	L	P	0	1	33	121	125	115	15	14	10	14	14	13	12	13	8	11	6
34	L	P	1	0	25	81	65	102	4	5	1	3	0	4	8	12	6	10	5
35	R	A	0	0	21	117	119	114	12	14	12	14	10	13	13	12	10	12	7
36	R	A	0	0	29	85	99	71	10	9	7	9	11	7	10	6	5	0	2
37	R	A	0	1	20	101	93	108	10	9	3	8	9	6	9	9	9	10	12
38	R	A	0	1	26	114	115	111	10	12	12	13	11	11	12	9	11	11	6
39	R	A	0	0	31	121	122	120	15	13	10	16	10	13	13	10	10	13	8
40	R	A	0	0	28	95	95	97	10	12	1	10	7	10	9	11	5	6	6
41	R	P	0	0	21	105	102	107	14	9	6	11	7	11	10	9	11	13	5
42	R	P	0	1	26	100	87	113	11	5	1	10	6	7	13	10	9	10	9

Subj.	Side	Loc	Dys	Vis	Age	FIQ	VIQ	PIQ	Inf	Com	Art	Sim	DSp	Voc	PCo	PAr	BlD	ObA	Dsy
43	R	P	0	0	22	110	104	115	10	11	10	9	9	8	14	8	10	14	9
44	R	P	0	1	20	106	112	102	13	12	7	13	11	14	10	6	7	11	7
45	R	P	0	1	22	96	97	93	9	8	9	8	9	7	8	9	5	10	5
46	R	P	0	0	24	120	114	129	13	11	16	8	10	6	14	11	15	10	16
47	R	P	0	0	28	109	106	111	11	13	9	8	9	10	8	9	15	9	8
48	R	P	0	1	24	125	133	118	16	12	17	13	16	14	15	9	12	11	8
49	R	P	0	1	29	118	121	112	14	13	13	14	9	11	13	8	10	11	8
50	R	P	0	1	19	115	114	114	13	13	10	14	8	11	13	11	10	12	8
51	R	P	0	0	20	127	128	123	14	16	15	14	11	13	14	12	12	12	11
52	R	P	0	0	21	101	102	98	10	10	9	11	7	10	8	7	12	8	6
53	R	P	0	0	27	111	113	107	11	9	10	13	13	11	14	9	7	10	6
54	R	P	0	0	22	117	110	123	10	13	6	14	11	12	14	14	12	12	9
55	R	P	0	0	25	94	101	88	8	10	9	11	7	11	6	5	6	7	6
56	R	P	0	0	29	119	122	118	15	13	15	12	9	14	15	11	13	7	9
								WAIS SCORES											
57	L	A	0	0	23	100	102	97	12	13	11	7	10	9	9	7	9	12	7
58	L	A	0	0	30	109	107	112	10	10	12	13	11	9	9	8	11	13	9
59	L	A	0	0	24	106	92	123	12	10	7	6	7	10	11	16	12	15	10
60	L	P	1	0	22	86	88	86	7	10	10	7	4	8	7	8	8	7	11
61	L	P	0	0	20	123	122	121	15	11	15	12	15	15	16	12	12	12	10
62	L	P	0	0	22	106	112	99	11	13	11	11	15	11	10	6	10	7	12

Subj.	Side	Loc	Dys	Vis	Age	FIQ	VIQ	PIQ[1]	Inf	Com	Art	Sim	DSp	Voc	PCo	PAr	BID	ObA	DSy
63	L	P	1	0	25	102	101	104	12	13	7	12	6	11	9	8	11	13	8
64	L	P	1	0	21	90	80	105	11	5	7	9	12	6	8	10	14	12	6
65	L	P	1	0	23	90	91	89	10	9	7	10	6	9	11	7	9	6	5
66	L	P	0	0	22	123	122	121	13	16	15	14	15	10	16	11	11	16	8
67	L	P	0	1	21	88	86	92	11	7	6	11	4	7	9	9	8	8	6
68	L	P	0	0	26	95	96	95	10	10	9	10	9	8	8	8	10	10	6
69	L	P	0	0	19	81	72	95	6	7	6	7	2	4	8	8	12	13	5
70	L	P	0	0	24	109	108	109	12	14	14	12	7	9	11	13	10	11	8
71	L	P	0	0	22	121	118	121	13	14	16	13	10	13	16	13	12	13	8
72	R	A	0	1	23	106	113	96	13	14	13	12	9	12	11	9	10	7	6
73	R	P	0	0	27	99	96	103	10	9	9	13	7	8	9	7	11	13	8
74	R	P	0	1	25	82	90	74	9	10	7	9	7	8	8	6	4	5	3
75	R	P	0	0	30	103	109	95	14	10	10	13	7	13	10	8	6	7	6
76	R	P	0	0	26	100	109	89	12	14	11	12	9	11	8	6	11	7	6
77	R	P	0	1	25	106	108	103	13	9	14	12	11	9	9	11	10	9	9
78	R	P	0	1	28	100	106	93	12	14	10	11	9	10	11	7	6	10	7
79	R	P	0	0	28	116	114	117	12	13	10	14	10	15	11	14	13	13	8
80	R	P	0	0	28	111	118	99	14	15	15	13	10	12	12	10	7	7	9

Appendix B

ANOVA SUMMARY TABLES FOR WAIS & W-B SCALES

Summary of Analysis of Variance of Wechsler-Bellevue Verbal IQ Scores

Source	SS	df	MS	F
Model	1929.34	3	643.11	3.16**
Side	791.60	1	791.60	3.89*
Locus	38.60	1	38.60	.19
Side x Locus	280.56	1	280.56	1.38
Error	10589.64	52	203.65	
Corrected Total	12518.98	55		

Summary of Analysis of Variance of Wechsler-Bellevue Arithmetic Subtest Scores

Sources	SS	df	MS	F
Model	150.17	3	50.06	3.57**
Side	61.42	1	61.42	4.38**
Locus	6.93	1	6.93	.49
Side x Locus	81.82	1	81.82	5.83**
Error	729.18	52	14.02	
Corrected Total	879.36	55		

Summary of Analysis of Variance of Wechsler-Bellevue Similarities Subtest Scores

Source	SS	df	MS	F
Model	44.55	3	14.85	1.73
Side	40.40	1	40.40	4.70**
Locus	.11	1	.11	.01
Side x Locus	1.18	1	1.18	.14
Error	447.00	52	8.59	
Corrected Total	491.55	55		

* $p < .10$

** $p < .05$

*** $p < .01$

Summary of Analysis of Variance of Wechsler-Bellevue Digit Span Subtest Scores

Source	SS	df	MS	F
Model	160.29	3	53.43	4.18**
Side	55.83	1	55.83	4.36
Locus	23.47	1	23.47	1.83
Side x Locus	18.46	1	18.46	1.44
Error	665.27	52		
Corrected Total	825.55			

Summary of Analysis of Variance of Wechsler-Bellevue Block Design Subtest Scores

Source	SS	df	MS	F
Model	68.87	3	22.96	3.21**
Side	5.60	1	5.60	.78
Locus	1.00	1	1.00	.14
Side x Locus	59.36	1	59.36	8.30***
Error	371.98	52	7.15	
Corrected Total	440.86	55		

Summary of Analysis of Variance of Wechsler-Bellevue Digit Symbol Subtest Scores

Source	SS	df	MS	F
Model	77.07	3	25.69	4.06**
Side	.11	1	.11	.02
Locus	6.48	1	6.48	1.02
Side x Locus	46.07	1	46.07	7.28***
Error	329.14	52	6.33	
Corrected Total	406.21	55		

* $p < .10$

** $p < .05$

*** $p < .01$

Summary of Analysis of Variance of Wechsler-Bellevue Digit Symbol Scores with Exclusion of Dysphasic Subjects

Source	SS	df	MS	F
Model	67.59	3	22.53	3.15**
Side	.01	1	.01	.00
Locus	7.79	1	7.79	1.09
Side x Locus	47.07	1	47.07	6.58**
Error	307.52	43	7.15	
Corrected Total	375.11	46		

Summary of Analysis of Variance of Wechsler-Bellevue Verbal IQ Scores with Exclusion of Subjects Showing Visual Field Defects

Source	SS	df	MS	F
Model	970.88	3	323.63	2.43*
Side	612.02	1	612.02	4.64**
Locus	32.59	1	32.59	.24
Side x Locus	96.19	1	96.19	.72
Error	4794.10	36	133.17	
Corrected Total	5764.98	39		

Summary of Analysis of Variance of Wechsler-Bellevue Comprehension Subtest Scores with Exclusion of Subjects Showing Visual Field Defects

Source	SS	df	MS	F
Model	23.67	3	7.89	1.48
Side	22.40	1	22.40	4.20**
Locus	.06	1	.06	.01
Side x Locus	2.92	1	2.92	.55
Error	191.83	36	5.33	
Corrected Total	215.50	39		

* $p < .10$

** $p < .05$

*** $p < .01$

Summary of Analysis of Variance of Wechsler-Bellevue Arithmetic Subtest Scores with Exclusion of Subjects Showing Visual Field Defects

Source	SS	df	MS	F
Model	84.18	3	28.06	2.66*
Side	6.94	1	6.94	.66
Locus	.77	1	.77	.07
Side x Locus	57.94	1	57.94	5.49**
Error	379.80	36	10.55	
Corrected Total	463.98	39		

Summary of Analysis of Variance of Wechsler-Bellevue Similarities Subtest Scores with Exclusion of Subjects Showing Visual Field Defects

Source	SS	df	MS	F
Model	39.80	3	3.27	2.10
Side	39.62	1	39.62	6.26**
Locus	1.74	1	1.74	.27
Side x Locus	3.62	1	3.62	.57
Error	227.70	36	6.32	
Corrected Total	267.50	39		

Summary of Analysis of Variance of Wechsler-Bellevue Digit Span Subtest Scores with Exclusion of Subjects Showing Visual Field Defects

Source	SS	df	MS	F
Model	87.57	3	29.19	2.87**
Side	33.15	1	33.15	3.26*
Locus	16.01	1	16.01	1.57
Side x Locus	13.75	1	13.75	1.35
Error	366.33	36	10.18	
Corrected Total	453.90	39		

* $p < .10$
** $p < .05$
*** $p < .01$

Summary of Analysis of Variance of Wechsler-Bellevue Block Design Subtest Scores with Exclusion of Subjects Showing Visual Field Defects

Source	SS	df	MS	F
Model	73.77	3	24.59	3.72**
Side	.29	1	.29	.04
Locus	.69	1	.69	.10
Side x Locus	57.20	1	57.20	8.64***
Error	238.23	36	6.62	
Corrected Total	312.00	39		

Summary of Analysis of Variance of Wechsler-Bellevue Digit Symbol Subtest Scores with Exclusion of Subjects Showing Visual Field Defects

Source	SS	df	MS	F
Model	57.94	3	19.31	2.58*
Side	4.40	1	4.40	.59
Locus	8.86	1	8.86	1.18
Side x Locus	25.26	1	25.26	3.37*
Error	269.83	36	7.50	
Corrected Total	327.78	39		

* $p < .10$

** $p < .05$

*** $p < .01$

Summary of Analysis of Variance of WAIS Similarities Subtest Scores

Source	SS	df	MS	F
Model	29.38	3	9.79	2.03
Side	15.42	1	15.42	3.20*
Locus	2.70	1	2.70	.56
Side x Locus	2.08	1	2.08	.43
Error	96.46	20	4.82	
Corrected Total	125.84	23		

Summary of Analysis of Variance WAIS Object Assembly Subtest Scores

Source	SS	df	MS	F
Model	52.79	3	17.60	2.01
Side	37.71	1	37.71	4.30*
Locus	1.08	1	1.08	.12
Side x Locus	16.49	1	16.49	1.88
Error	175.21	20	8.76	
Corrected Total	228.00	23		

Summary of Analysis of Variance WAIS Object Assembly Subtest Scores with Exclusion of Dysphasic Subjects

Source	SS	df	MS	F
Model	61.76	3	20.59	2.63*
Side	47.90	1	47.90	6.13**
Locus	.03	1	.03	.00
Side x Locus	9.90	1	9.90	1.27
Error	125.04	16		
Corrected Total	186.80	19		

* $p < .10$

** $p < .05$

*** $p < .01$

Summary of Analysis of Variance of WAIS Similarities Subtest Scores with Exclusion of Subjects Showing Visual Field Defects

Source	SS	df	MS	F
Model	38.40	2	19.20	3.77**
Side	20.71	1	20.71	4.07*
Locus	8.32	1	8.32	1.64
Error	81.39	16	5.09	
Corrected Total	119.79	18		

NB - Side x Locus interaction could not be computed because of limited cell sizes

* $p < .10$
** $p < .05$

VITA AUCTORIS

Clare F. Brandys was born on August 8, 1960 in Chicago, Illinois. In June, 1978 she graduated as valedictorian from Dixon High School, Dixon, Illinois. In September, 1978, she enrolled at Loyola University of Chicago. She graduated with a Bachelor of Science, magna cum laúde, in Psychology and English in January, 1982 and continued in the graduate psychology programme at Loyola University in the Spring of 1982. Since September, 1982 she has been enrolled in the Doctoral programme in neuropsychology at the University of Windsor. She is presently interning as a psychometrist/research assistant at the Regional Children's Centre in Windsor, Ontatio.